

Aircraft Hydraulic System Pump: A Reliability Analysis

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ABSTRACT

This paper examines typical failures of the hydraulic pumps of aircraft with the purpose of determining the reliability of the pumps. In this work, pumps were classified based on design features. Statistics of typical failures and malfunctions of the hydraulic pumps of Russian aircrafts such as NP-107, NP-72MV, NS-63, NS-46-2, NP-89D were collected with the aim of conducting a quantitative and qualitative analysis of reliability. The type of histograms, and, also the physical nature of the failure, indicated that the law of distribution of failures is close to log-normal. The theoretical law of the distribution of the operating time of a part before failure was used to determine gamma-percent resource. According to the calculation, it was found that the gamma-percent resource $\gamma = 10\%$ is satisfied, therefore, the reliability level is sufficient.

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INTRODUCTION

The effectiveness of the use of Aviation Technology largely depends on its operational qualities, on the timely determination and elimination of the causes of failures and malfunctions [1-2]. The most important issue in the analysis of the operational efficiency of an aircraft is the conformity of its design to the operational requirements of its manufacture and the problem of increasing operational reliability [3].

The aircraft pump is considered as an object of this analysis. Pumps are machines

which are used for creating a pressure flow of a liquid medium [4]. This flow is created as a result of the force acting on the liquid in the pump chamber. Volumetric pumps are distinguished by the nature of the effect of force, and, consequently, by the type of the working chamber. In a volumetric pump, the force on the liquid occurs in the working chamber, periodically changing its volume and alternately connecting the inlet and outlet of the pump [5-6]. Various classification of pumps are shown in Figures 1-6

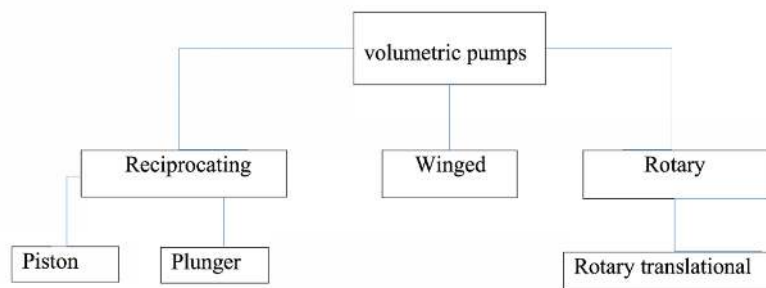


Fig 1 – Classification of volumetric pumps

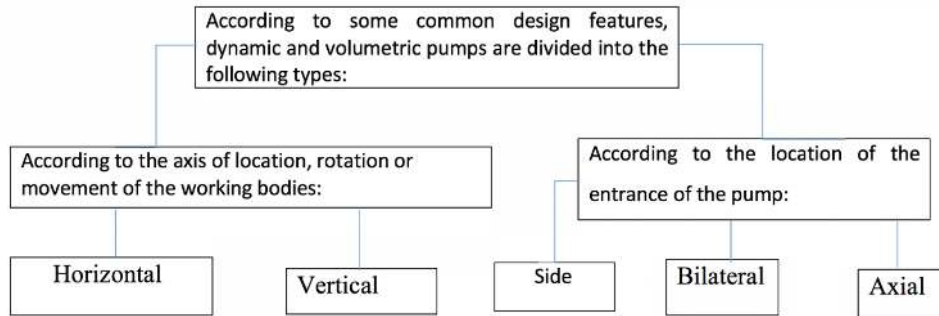


Fig 2 – Classification of pumps based on design features

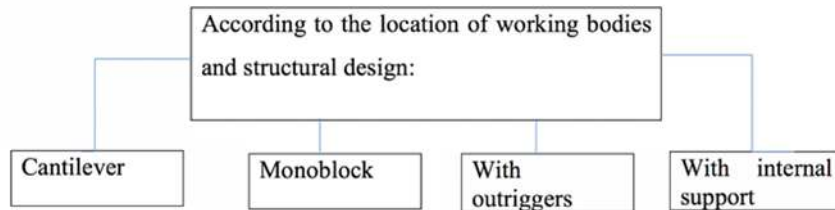


Fig. 3 – Classification of pumps based on the location of working bodies and structural design

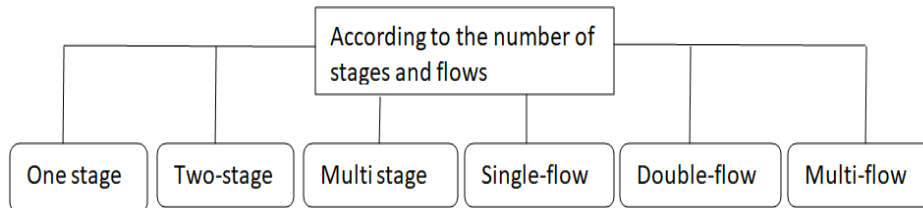


Fig 4 – Classification of pumps based on the number of stages and flows

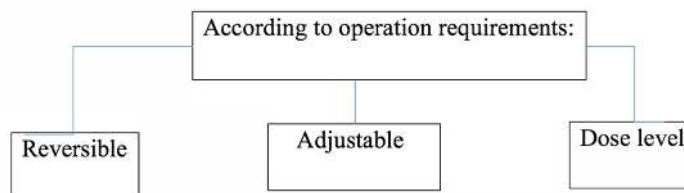


Fig. 5 – Classification of pumps based on operation requirements



As shown in Fig. 1 volumetric pumps are basically classified into two: reciprocating and rotary. A reciprocating pump is a class of positive-displacement pumps that includes the piston pump, plunger pump, and diaphragm pump. Well maintained, reciprocating pumps can last for decades. Unmaintained, however, they can succumb to wear and tear. It is often used where a relatively small quantity of liquid is to be handled and where delivery pressure is quite large. In reciprocating pumps, the chamber that traps the liquid is a stationary cylinder that contains a piston or plunger [9]. Positive displacement rotary pumps are pumps that move fluid using the principles of rotation. The vacuum created by the rotation of the pump captures and draws in the liquid. Rotary pumps are very efficient because they naturally remove air from the lines, eliminating the need to bleed the air from the lines manually [10].

According to some common design features, pumps are divided into horizontal, vertical, bilateral, side and axial, as shown in Fig. 2. A horizontal centrifugal pump will have its shaft placed horizontally, typically between the bearings or overhung. Meanwhile, a vertical centrifugal pump has a shaft that is oriented vertically [11]. A side channel pump, also known as liquid ring pump is a type of self-priming multistage pump, having characteristics of that of a positive displacement pump. Side Channel pumps are quite unique in terms that they can handle up to 50% of entrained gas with fluid and vapour taking different paths through the pump. They contain multiple impellers similar to a multistage pump, however the design of the impellers are slightly different being more like a multistage peripheral pump [12]. An axial flow pump is a type of dynamic pump which has a suction parallel to the impeller direction. An axial flow pump doesn't change the flow direction of the fluid. In this pump, the fluid enters and exits the pump in the parallel direction to the impeller. It has an impeller inside the pipe. This pump has three to four blades that are installed on the impeller [13].

Fig 3 shows the classification of pumps according to the location of working bodies and structural design. These include cantilever and monoblock pumps; pumps with outriggers and those with internal support. A

cantilever pump is a specialized type of vertical sump pump designed to be installed in a tank or sump but with no bearing located in the lower part of the pump. Thus, the impeller is cantilevered from the motor, rather than supported by the lower bearings [14]. A Monoblock pump is a mechanical device in which a common shaft contains the rotating parts. Owing to this, during the transmission from motor to shaft, there is less loss of energy. Since there are 7% losses in belt driven sets and 3% losses in coupling driven sets hence to avoid these transmission losses Mono block pump sets evolved. Mono means single, as its name suggests Monoblock Horizontal Multistage Pump is a non-self-priming centrifugal pump. This means that the Pump unit is rigidly connected i.e. attached with long shaft electric motor. The compact structure renders small size of pump; axial inlet and radial outlet. Outrigger pump is a pump whose bearings are isolated from the pumped liquid. Internally supported pumps are pumps whose bearings are in contact with the pumped liquid.

According to the number of steps and flows, pumps are classified into one-stage, two-stage, multistage, Single-flow, Double-flow, and Multi-flow. A single-stage centrifugal pump consists of one impeller rotating on a shaft within a pump casing which is designed to produce fluid flow when driven by a motor. It is one of the simplest designs of pumps available and many variations in design exist to satisfy the duty requirements of applications. Impeller design is changed to accommodate clean, dirty and solid laden liquids, with several mechanical seal types to accommodate variations in applications. [15]. A two-stage pump has two suction impellers operating side by side. The operator must decide if he wants volume or more pressure by selecting a switch on the pump panel. Multistage pumps are defined as pumps in which the fluid flows through several impellers fitted in series. Multistage centrifugal pumps are applied to make high pressure on the shaft in the same housing, which is more economical than a pump with a single impeller. As part of the pump structure, the channels within the pump housing work by directing an impeller discharge to suck the other. [16]. Single-flow pump is a pump in which the liquid medium is

supplied through one outlet. Double-flow pump is a pump in which a liquid medium is supplied through two outlets. Multi-flow pump is a pump in which a liquid medium is supplied through several outlets.

And finally in Fig 5, pumps were classified based on operation requirements as reversible, adjustable and dose level. Reversible pumps are used for some special applications, and their rotation verse is alternately clockwise and counterclockwise. An adjustable displacement pump has a method of increasing or reducing displacement either manually, hydraulically or electronically. The method of displacement change depends upon the pump's structure, differing between piston and vane pumps, and between those two,

iterations still. A dosing pump, which is a positive displacement pump, is designed to inject a chemical or another substance into a flow of water, gas, or steam. Dosing pumps, which are typically small, provide an extremely precise flow rate for maximum control. They are the central part of an integrated dosing system designed for the automatic dispersion of chemicals. This dosing definition applies to a wide range of applications and industries, from wastewater treatment to food processing [17].

Based on the peculiarities of constructing plunger pumps, their hydraulic parts are divided into single (single) action pumps - for example NP-89 and double (double-sided) action - for example NP-72MB [1].



Figure 6 – NP-89



Figure 7 – NP-72MV

Data Collection and Analysis

Statistics of typical failures and malfunctions of the hydraulic pumps of Russian

aircrafts were collected: NP-107, NP-72MV, NS-63, NS-46-2, NP-89D.

To analyze the reliability of the pump, a qualitative analysis was performed based on statistical data. Failures were grouped by parts

and by the nature of the failures. Results of failure grouping are presented below as bar graphs.

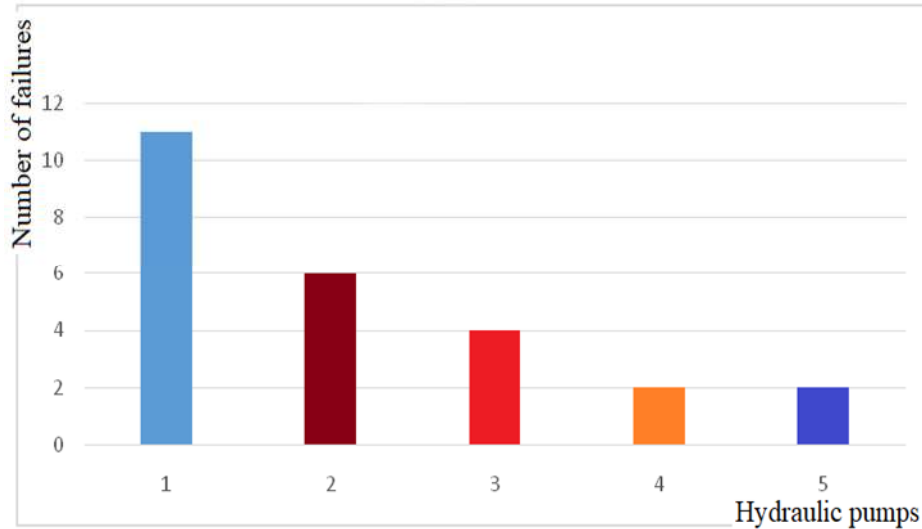


Figure 8 – Distribution of failures of the hydraulic pumps

1- NP-89D, 2 - NS-46-2, 3 - NP-107, 4 - NP-72MV, 5 - NS-63,

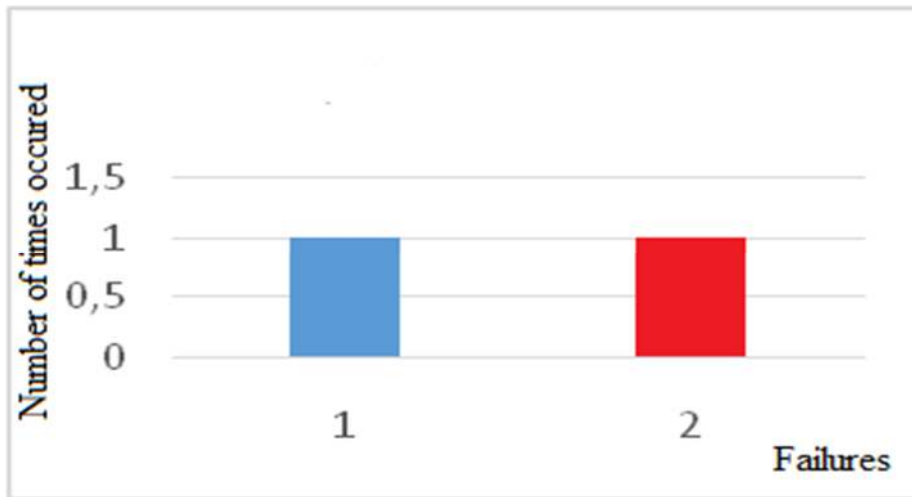


Figure 9 – Distribution of failures found on NS-63

1 - Destruction of the pumping node of NS-63; 2- Clogged filter and inlet throttle of NS-63.

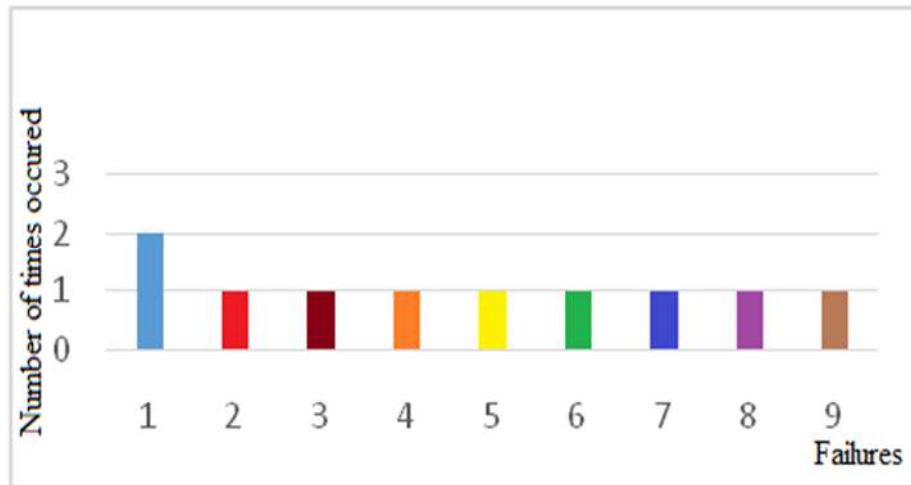


Figure 10 – Distribution of failures found on NP-89D

- 1 - Crack on the pump mounting flange; 2- Discoloration on the parts of the pump;
- 3- Pressure drop to zero; 4- Leakage of AMG-10;
- 5- Extraneous noise and the presence of chips; 6- External part not air tight;
- 7- Destruction of the pumping part; 8- The pump turning around its axis;
- 9- Slicedrive spring of NP-89.

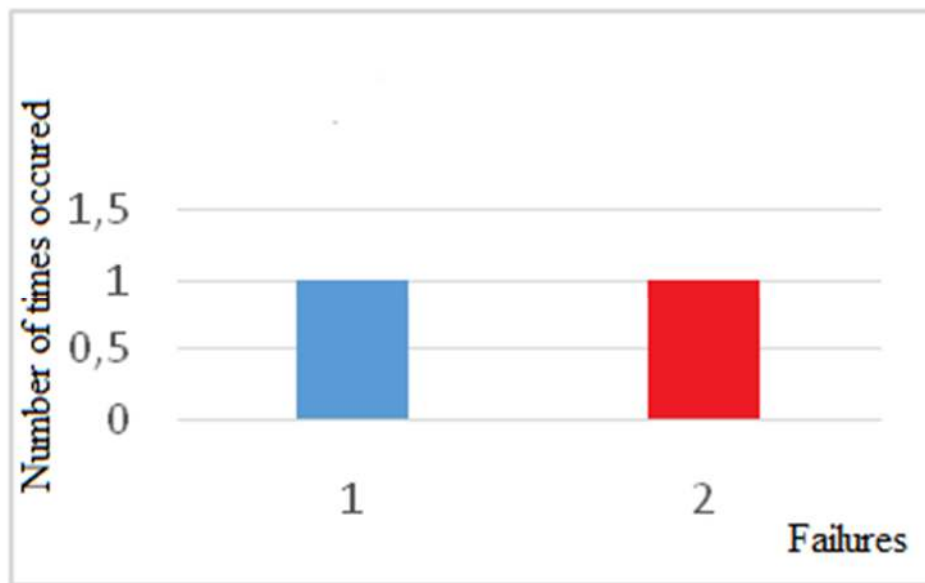


Figure 11 – Distribution of failures found on NP-72MV

- 1-Wear and damage to parts; 2- Leakage of AMG-10 through the drain fitting.

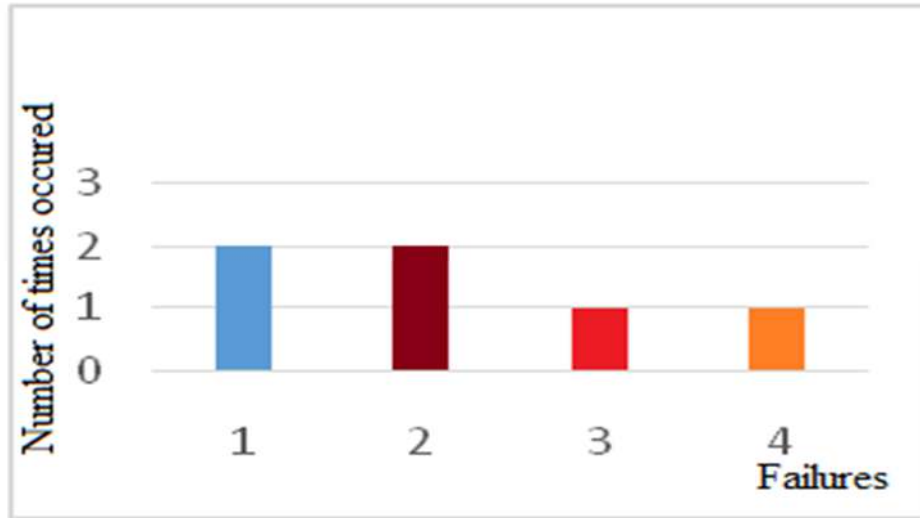


Figure 12 – Distribution of failures found on NS-46-2

1- Lack of pressure in the hydraulic system; 2- Does not create pressure; 3-Dust particles on the filter; 4- Internal leakage.

A quantitative analysis of reliability was made in order to determine the theoretical law of the distribution of the operating time of a part before failure and the parameters of this law, which makes it possible to assess the actual reliability of the part within the assigned resource, as well as to determine the need for measures aimed at increasing the reliability level of that part and ensuring the regularity of flights.

In the calculation, the empirical density of the distribution of failures, the empirical intensity of the occurrence of failures and the empirical probability of failure-free operation are determined. The results obtained are tabulated and histograms of empirical characteristics were drawn based on the results. Looking at the type of histograms, and, also based on the physical nature of the failure, it was found that the law of distribution of failures is close to log-normal. A calculation was also made to determine the accuracy of the distribution parameters. In the calculation, the upper and lower boundaries of the accuracy intervals for the parameters, the quantile of the normal distribution, the percentage resource, the lower estimate $P_n(t)$, and the Quantile corresponding to the probability of 0.0001 are determined.

CONCLUSION

The use of Aircrafts largely depends on reliability and safety. Thus, safety can only be achieved with an effective maintenance program which involves detecting failures on time before they cause accidents and eliminating the causes of the failures as well. Hydraulic pumps are essential part of the hydraulic system of an aircraft, hence the need to ascertain the working efficiency of the pumps. In this work, hydraulic pumps were classified into various groups based on design features and operational requirements. In addition to that, a quantitative analysis of reliability was carried out on an hydraulic pump in order to determine the level of reliability. Taking the significance level $\alpha = 10\%$, the number of degrees of freedom $r = 5$ and the critical value $X^2_{cr} = 9.24$. The degree of discrepancy between the theoretical and empirical distributions of failures, $U^2 = 6.7291$, does not fall into the critical region: $(9.24; +\infty)$. Therefore, we can accept the hypothesis of a log-normal distribution law. According to the calculated value of U^2 , and from the table of the relationship between U^2 and γ , the condition for the gamma-percent resource is satisfied, therefore, the reliability level is sufficient.



REFERENCES

1. Voloshina, A., Panchenko, A., Panchenko, I., Titova, O. and Zasiadko, A., 2019, December. Improving the output characteristics of planetary hydraulic machines. In *IOP Conference Series: Materials Science and Engineering* (Vol. 708, No. 1, p. 012038). IOP Publishing.
2. Khan, K., Sohaib, M., Rashid, A., Ali, S., Akbar, H., Basit, A. and Ahmad, T., 2021. Recent trends and challenges in predictive maintenance of aircraft's engine and hydraulic system. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 43(8), pp.1-17.
3. Zhang, X., Bowman, C.L., O'Connell, T.C. and Haran, K.S., 2018. Large electric machines for aircraft electric propulsion. *IET Electric Power Applications*, 12(6), pp.767-779.
4. Abanihi, V. K., Ezomo, P. I., Aliu, D., Chinedu, P. U., Obari, J. A., & Momoh, M. O., (2020). "Complementarity Problem Approach to Economic Power Dispatch of Nigeria Power System". *ATBU Journal of Science, Technology and Education*, 8(2), 240-249, June 2020.
5. Zhang, X., Bowman, C.L., O'Connell, T.C. and Haran, K.S., 2018. Large electric machines for aircraft electric propulsion. *IET Electric Power Applications*, 12(6), pp.767-779.
6. Abubakar U, Zaharuddeen H, Umar M, Shehu A.M, Momoh M. O., (2019) "Graphical User Interface (GUI) Based Position and Trajectory Tracking Control for the Ball and Plate System Using H-Infinity Controller", *Covenant Journal of Informatics and Communication Technology*, Vol. 5 No. 1, June, 2019
7. Enrico, Z.I.O., Mengfei, F.A.N., Zhiguo, Z.E.N.G. and Rui, K.A.N.G., 2019. Application of reliability technologies in civil aviation: Lessons learnt and perspectives. *Chinese Journal of Aeronautics*, 32(1), pp.143-158.
8. Sharypov, A., Brushnikin, V., Koval, S., Glukhov, G. and Gubanov, O., 2018. Aircraft components life cycle monitoring as a tool for identifying inauthentic aviation equipment items. *International Journal of Mechanical Engineering and Technology (IJMET)*, 9(7), pp.612-620.
9. Goncharenko, A., 2018. Development of a theoretical approach to the conditional optimization of aircraft maintenance preference uncertainty. *Aviation*, 22(2), pp.40-44.
10. Dam, Gert. "PUMPS - TYPES & OPERATION - RECIPROCATING (PISTON) PUMPS". articles.compressionjobs.com. Retrieved 2016-12-21
11. Shengrong, G. U. O., Jinhua, C. H. E. N., Yueliang, L. U., Yan, W. A. N. G., & Hongkang, D. O. N. G. (2020). Hydraulic piston pump in civil aircraft: Current status, future directions and critical technologies. *Chinese Journal of Aeronautics*, 33(1), 16-30.
12. Hetzer, R., Del Maria Javier, M. F., Dandel, M., Loebe, M., & Delmo, E. M. J. (2021). Mechanical circulatory support systems: evolution, the systems and outlook. *Cardiovascular diagnosis and therapy*, 11(1), 309.
13. Yu, J. (2022). *Mechanical Science. In Fundamental Principles of Nuclear Engineering* (pp. 465-542). Springer, Singapore.
14. Sreekanth, M., Sivakumar, R., Sai Santosh Pavan Kumar, M., Karunamurthy, K., Shyam Kumar, M. B., & Harish, R. (2021). Regenerative flow pumps, blowers and compressors—A review. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 235(8), 1992-2013.
15. Kan, K., Zheng, Y., Chen, Y., Xie, Z., Yang, G., & Yang, C. (2018). Numerical study on the internal flow characteristics of an axial-flow pump under stall conditions. *Journal of Mechanical Science and Technology*, 32(10), 4683-4695.
16. Marscher, W. D. (2022). Rotordynamic Analysis. *Design, Modeling and Reliability in Rotating Machinery*, 1-55.
17. Yin, Y. (2020). High-Temperature and High-Speed Gas Turbine Pump Electro-Hydraulic Energy System for Aircraft. *In High Speed Pneumatic Theory and Technology Volume II* (pp. 51-161). Springer, Singapore.
18. Li, Y. B., Fan, Z. J., Guo, D. S., & Li, X. B. (2020). Dynamic flow behavior and performance of a reactor coolant pump



- with distorted inflow. Engineering Applications of Computational Fluid Mechanics, 14(1), 683-699.*
19. Lyu, L., Chen, Z., & Yao, B. (2019). *Energy saving motion control of independent metering valves and pump combined hydraulic system. IEEE/ASME Transactions on Mechatronics, 24(5), 1909-1920.*